Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Inquiry Regarding Software Defined Radios	)	ET Docket N0. 00-47
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<u>COMMENTS OF SHARED SPECTRUM COMPANY</u>

SUMMARY

Shared Spectrum Company is a newly formed enterprise that seeks to establish a new type of communications network to derive considerable broadband data capacity using software defined radio equipment on a secondary basis in the spectrum "holes" in currently allocated bands such as that for television broadcasting.

The Commission should grant Shared Spectrum an experimental license to establish the parameters of its system -- which has the potential of greatly expanding the effective communications capacity of the spectrum. The system is designed to locate free spectrum and dynamically allocate bandwidth in a reliable and economic way. Part 2 of the Commission's Rules should be revised to make available at least on a secondary basis use of fixed and mobile services available on most bands under 3 GHz. The Commission should remove that and other artificial impediments to rapid implementation of technology that can enable the market to meet the public needs that are now thwarted by spectrum limitations. This innovation will particularly benefit underserved rural areas of the country that cannot now be economically served by other means of providing broadband Internet access.

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I. INTRODUCTION

Shared Spectrum Company hereby comments on the Commission's Notice of Inquiry, 15 FCC Rcd 5930 (2000), concerning the technical and regulatory implications of software defined radios (SDR). SDR is one of the most exciting and promising communications technologies ever introduced and will have tremendous impact on communications. SDR is the key enabling technology that will enable individuals to have a wide variety of communication options where ever they are. SDR will bring the power of computers and computer networks to people's day-to-day lives similar to impact computer networks have had on modern business. Its use is the key to the goal stated by Chairman Kennard "that spectrum become like any other commodity that flows fluidly in the marketplace."[1] It is the key to a profound increase in the capacity of the spectrum to provide communications services. As Commissioner Ness observed in her statement in the Notice Of Inquiry, "SDR holds the potential to enhance our participation in the global economy, to access new services, and to utilize the spectrum more efficiently."

[1] Statement of May 31, 2000 at the Public Forum on Facilitating Secondary Markets in Spectrum.

Shared Spectrum is a newly formed company that includes experts in the technical and regulatory aspects of SDR. Our goal is provide communications equipment that will provide high capacity data transmission by reusing spectrum in the TV bands and other bands below 3 GHz as a secondary user. There are 50 to 200 MHz of spectrum available alone in the TV bands, that are optimal for non-line-of-sight propagation. Use of that unused capacity will enable economic, high speed Internet connectivity in rural and other areas were other approaches are economically unfeasible. Rural areas have the largest amount of available spectrum because they have less broadcast TV coverage. Shared Spectrum submits that secondary spectrum usage is the way to bridge the “rural Internet divide”.

II. THE LARGE AMOUNT OF SPECTRUM AVAILABLE FOR SECONDARY USE IN THE TV BANDS

As an illustration of the sparsity of current use of the TV bands, we show, in Figure 1 below, the predicted Channel 24 Grade B (64 dBu) coverage area using the FCC propagation model “tvfmfs” and the FCC station database. The center of the plot is Washington, D.C. (WDC). The station ID and the station type (TV=regular television, DT=digital television, TX=repeater) are shown for each station within 300 km of Washington. The solid lines show the P(50,50) coverage and the dashed lines show the P(50,10) which are coverages for 50% of the locations 50% and 10% of the time respectively. Clearly there are large areas between the coverage circles where the spectrum is not useful for TV and could be used for other purposes. The FCC propagation model “tvfmfs” doesn’t reflect terrain effects, which if taken into account would show even smaller TV coverage areas.

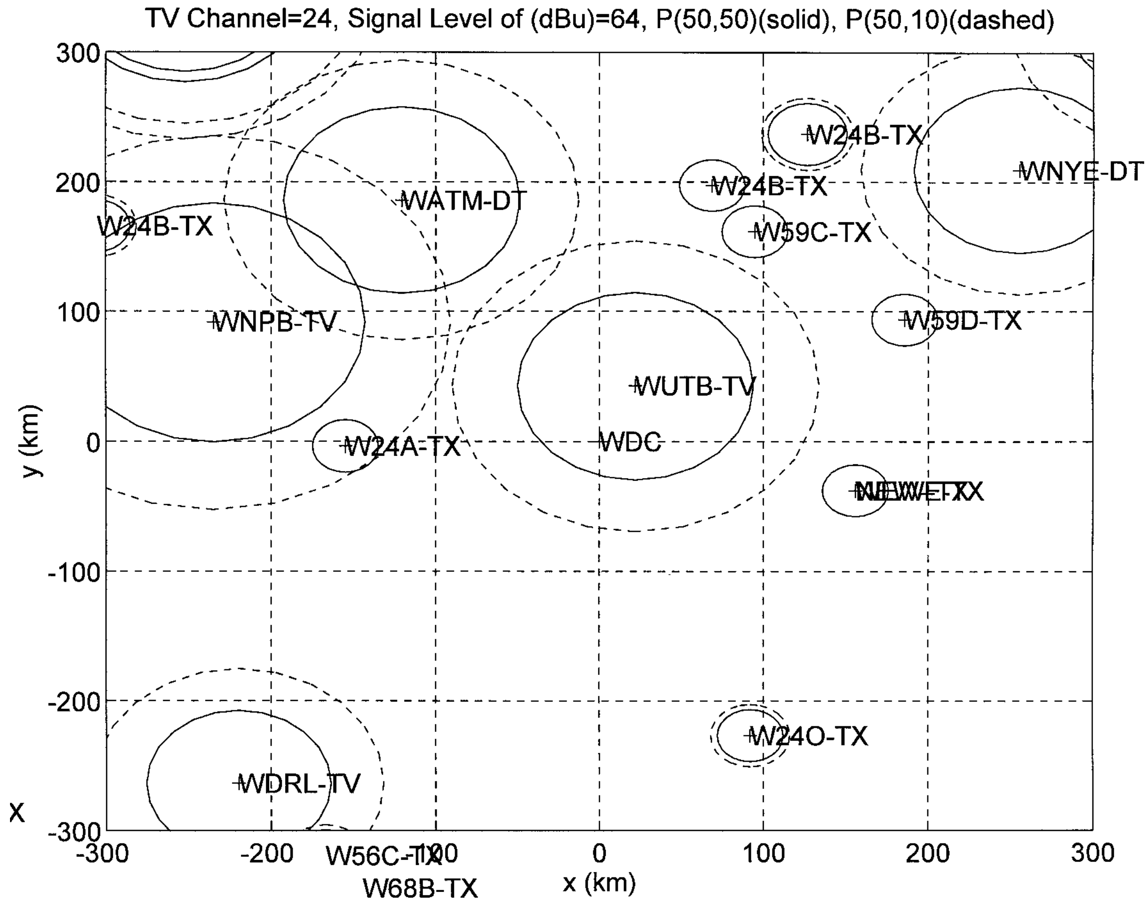

Figure 1 Predicted coverage of TV channel 24 in the region centered on Washington, D.C..

In Figure 2, below, we show, as a further illustration, the predicted P(50,50) field strength of all channels at the eastern tip of West Virginia (-100 km, 100 km relative to Washington, D.C.) along with the Grade A, Grade B and thermal noise levels. Approximately 6 channels are above Grade A coverage limits while most channels are well

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below Grade B. At this location, most of the TV spectrum is available for other uses. This pattern is characteristic of many rural areas of the country.

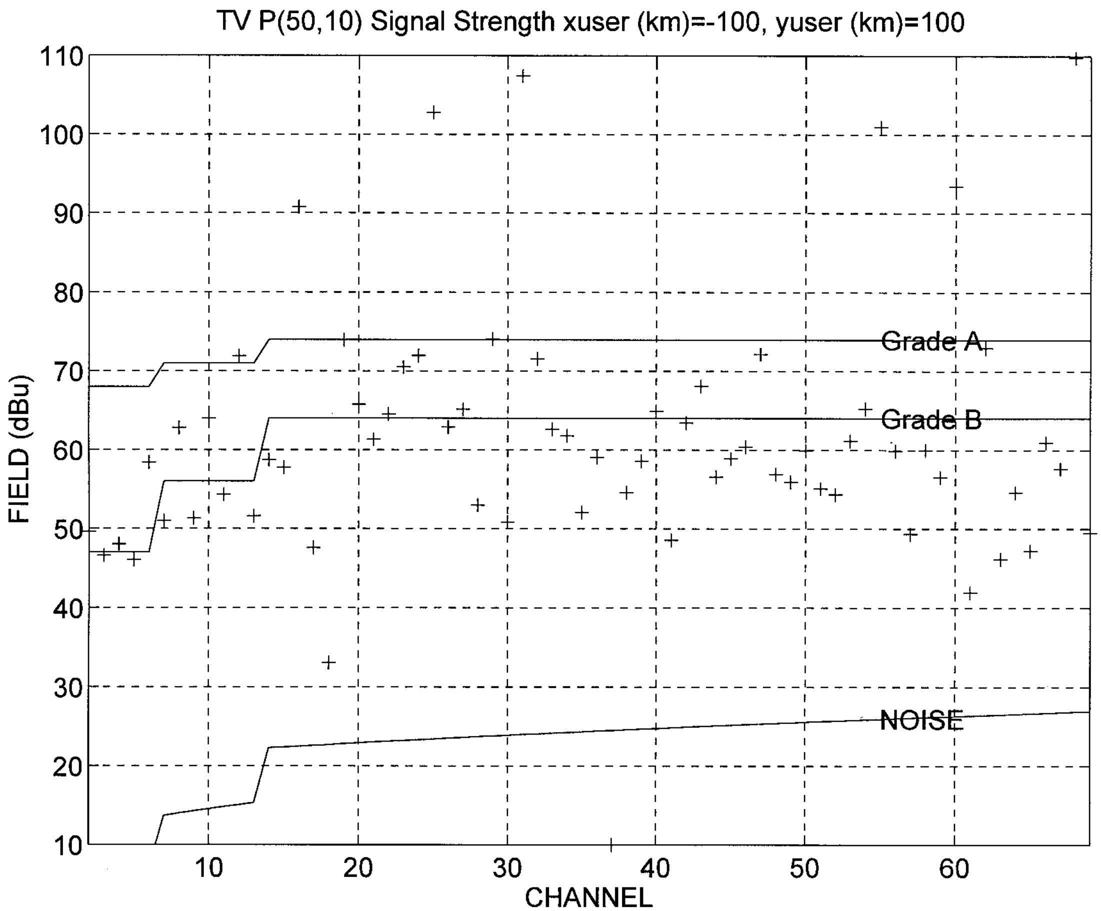

Figure 2 Predicted strength of all TV channels at a location 100 km west and 100 km north of Washington D.C. (the northeastern part of West Virginia).

In Figure 3, below, we show the number of available channels at all locations relative to Washington, D.C. on the basis of the criterion that the channel is available if the field strength of the sum of all stations at this channel added together is at least 20 dB

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less than the P(50,50) Grade B field strength value. In the Washington area, there are 14 channels (84 MHz) open and in rural areas there are 40-50 channels (240-300 MHz) open. These estimates, moreover, do not reflect the effects of terrain blockage which is likely to increase these values.

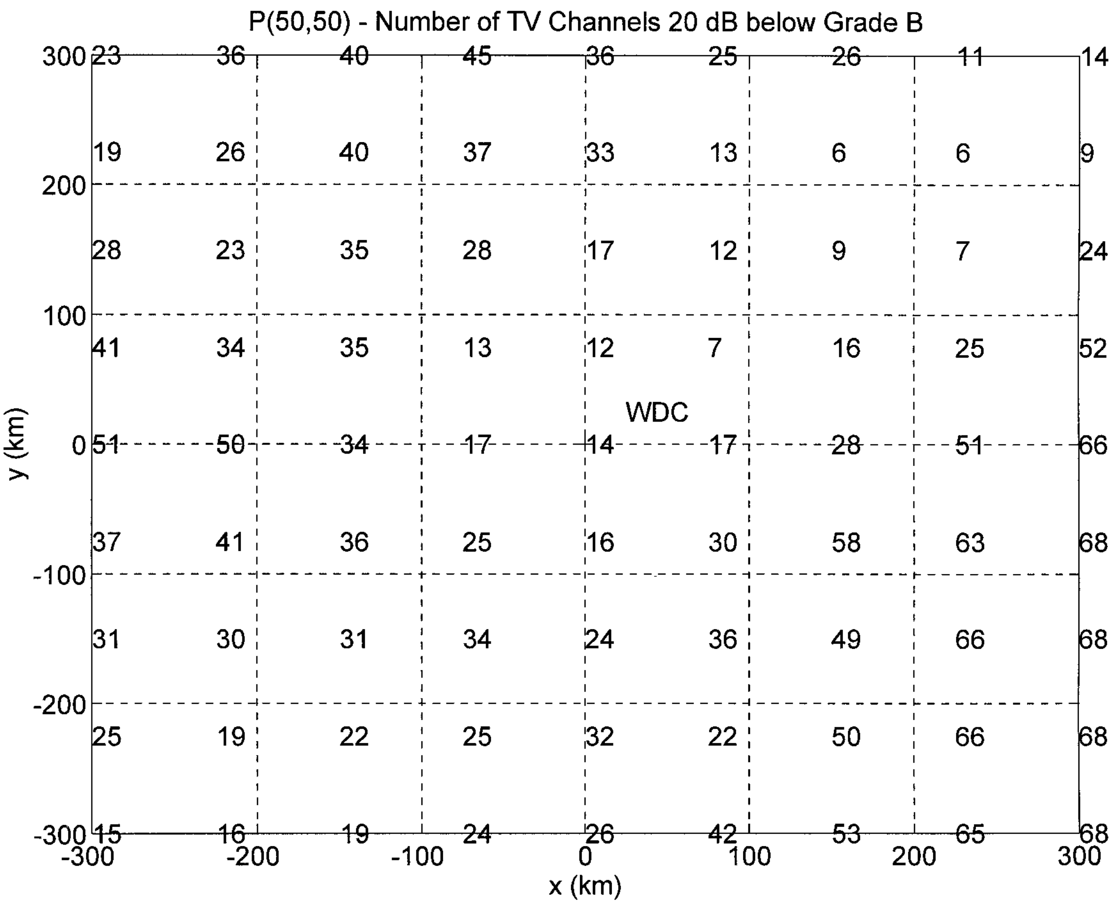
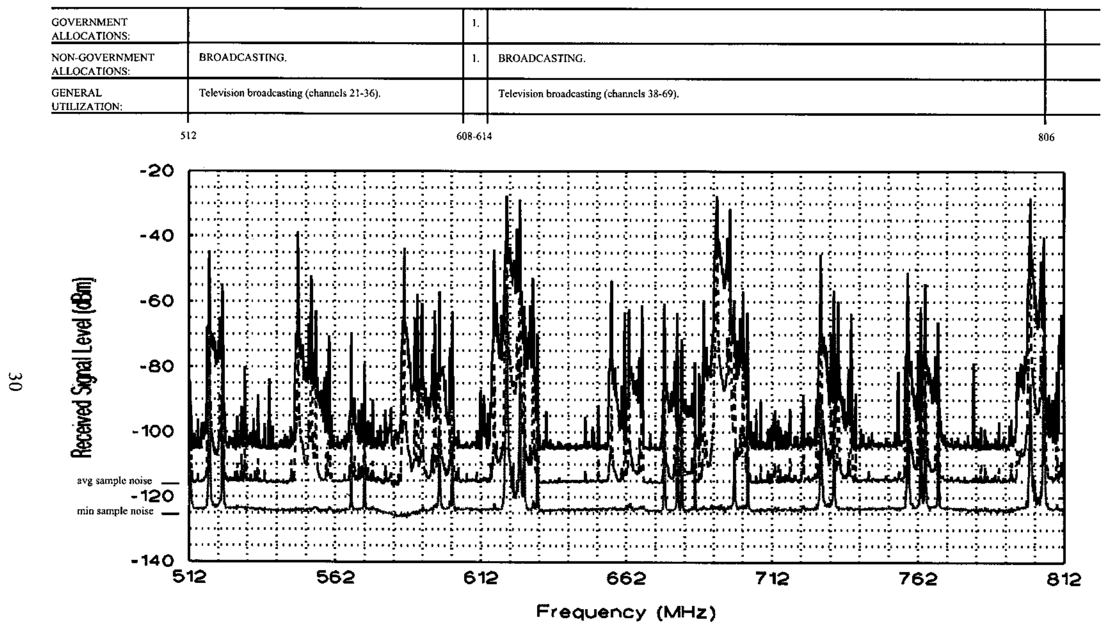


Figure 3 The number of TV channels available for secondary usage at different locations about Washington, D.C.

The Government has conducted measurements that support these predictions. Figure 15 below shows a spectrum survey graph covering TV channels 21 to 69 from the report entitled “Broadband Spectrum Survey at San Diego, California” [2]



1. RADIO ASTRONOMY. No stations are authorized to transmit in this band.

Figure 15. NTIA spectrum survey graph summarizing 5,800 sweeps across the 512-806 MHz range (System-1, band event 21, swept/m3 algorithm, sample detector, 100-kHz bandwidth) at San Diego, CA, 1995.

While numerous TV stations are present, there are significant spectrum gaps in-between. These measurements where made at location that had good line of sight to a large urban area. In rural areas, the TV coverage is much less than in urban areas and as a result the spectrum holes will be much larger.

Low power, distributed, cellular communications system could use this spectrum with minimal impact to the number of people able to receive TV. With careful engineering of the base station locations, the use of directional antennas, aggressive power management for each link, the use of multipath mitigation waveforms such as OFDM, and

[2] NTIA Report 97-334, http://www.its.bldrdoc.gov.

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other proprietary techniques, we will be able to use milliwatts to send vast amounts of data to rural users and have minimal impact to the TV audience. The technology for this exists now and could be widely fielded in 1-2 years.

III. PROPOSED COMMISSION ACTIONS

Up to now, the rules regarding secondary spectrum usage have stifled innovation in this area. The growth of radio and network technology has exploded in the last 10 years and is ready to be applied to the spectrum management problem. While there are technical problems to overcome, regulatory issues are now the dominant issue. We urge the FCC to: (1) support early and large scale testing of this technology, (2) move towards changing the rules in bands such as TV where there is significant secondary bandwidth that would warrant technology development, and (3) work with industry to resolve the property and contract questions potentially related to this application of secondary spectrum usage.

If impediments are removed, SDR technology will greatly increase the efficiency of radio frequency communications in 20 to 30 years. Low-cost broadband tuners coupled with SDRs will allow the frequency and waveform of each transmission to be optimized to the propagation path, available connecting infrastructure and data type. There will be a unified standard consisting of several waveforms and protocols (not the hundreds we have today) which will allow devices to use a common radio frequency infrastructure. Any other end result would be like having multiple, redundant "stovepipe" wired Internet infrastructures today. The high costs of the wired infrastructure forced the world to a common IP protocol and shared resources. The same will occur in the radio spectrum.

Spectrum will not be limited to narrowly defined uses by a relatively small number of licensees. It will be rented for the moment it is used and then released for others' use -- just as in the wired world.

The technology required for re-use of the television spectrum exists today in a variety of Department of Defense and commercial projects, but has not yet been integrated. In the past, there has been a technology barrier resulting from the lack of low-cost and low-power signal processing. But now the current generation of DSPs and ASICs has sufficient processing power for demodulating complex waveforms and hosting the complexity of required algorithms. Within a few years, DSPs and ASICs will be power-efficient enough for very capable SDR handheld devices. There are already low-power, low-cost broad-band handheld receivers from ICOM and others that cover the TV bands. Enabling broad band transceivers to be able to demodulate complex waveforms and providing them with algorithms to select the correct waveform is a near term event -- not a distant goal.

The present application of secondary usage of the TV band is an ideal stepping stone on the path to the ultimate vision.

(1) Our proposal is focused on and will answer critical technical questions related to interference mitigation. We selected a fixed application because it is technically easier, and it is easier to do repeatable experiments. The technical approach is also applicable to mobile applications, and we plan to pursue this use after successful fixed service testing.

(2) The TV band has enough spectrum available for reuse to warrant the private investment required for significant development and testing.

(3) The technology will provide unique benefit to rural Americans who are being left behind in the digital divide, so that there will be strong national interest in solving this problem. This type of broad bandwidth wireless communications in bands the permit non-line of sight communication may be the only method to provide connectivity to rural America.

IV. RESPONSES TO THE COMMISSION'S SPECIFIC QUESTIONS

In this section, we respond to specific questions raised in the Notice of Inquiry Related to Improving Spectrum Efficiency and Spectrum Sharing.

A. To What Extent Could Software Defined Radios Improve the Efficiency of Spectrum Usage?

The Notice of Inquiry suggests two new and distinct methods to increase efficient use of the spectrum: (1) to identify unused blocks of spectrum in certain regions and to use this spectrum as the primary user, and (2) to identify unused blocks of spectrum in certain regions and to use this spectrum as the secondary user.

In the first method, the radio is reconfigurable and can operate in multiple bands and with multimodes. Via some external method such as an auction or agreement with the license holder, the radio is assigned a frequency, modulation and networking parameters. These parameters are loaded into the radio and it enters the appropriate network. The radio does not identify unused spectrum or make decisions except possibly to switch approved modes. The radio may identify useful channels/modes which it can close the link, independent of the interference it may cause other users. Changes to the channel/mode could be made in fractions of a second. It may rank the choice of channel/mode to minimize it's transmitted energy level, which would greatly improve spectrum reuse. In the limit, such a radio may be given a list of prohibited frequencies and be allowed to use the remaining spectrum as required.

This new radio type is the object of significant research at the Department of Defense's Defense Advanced Research Projects Agency (DARPA). The goal is to increase the capacity of mobile, tactical terrestrial radio networks. This new type of radio is expected to increase the capacity of tactical networks by two orders of magnitude and will be a key force multiplier as will enable the use of semi-autonomous robots, large numbers of unmanned air-vehicles (UAVs), and video camera sensors.

Detailed estimates of how this technology would increase spectrum efficiency are highly dependent on the current spectrum usage and the type of proposed secondary service. Several spectrum studies have been conducted by NTIA in metropolitan areas. The NTIA San Diego report discussed above consists of spectrum plots from 108 MHz to 19,700 MHz in multiple bands measured at a single location with maximal line-of-sight coverage to increase the probability of detection of weak signals. These studies show that there are many unused parts of the spectrum.

B. What particular functions related to spectrum usage could a software defined radio perform? Could it locate free spectrum, dynamically allocate bandwidth, and enable better sharing of the spectrum?

Spectrum engineering is a very complex process for a variety of reasons. Propagation effects are very difficult to measure and predict. It is very difficult to diagnose why a radio link fails and hard to attribute the failure to interference versus other causes. There are many different types of communications equipment that have very different properties. Also, communication systems are isolated from one another, which required significant effort by engineers to understand how the systems interacted.

In addition, older communication systems had limited ability to overcome interference. They used analog modulations that required high signal to noise ratios. The radio operation was fixed, with minimal power control or frequency control to overcome interference. Small levels of interference would destroy service. Sources of interference were very hard to identify, and communications equipment was inflexible so that interference was very expensive to overcome. These issues led to the present conservative spectrum management policy of each system type separated by frequency and space.

We believe that software defined radios and communications networks can mitigate all of these issues. A network of software defined radios acting as a distributed measurement system and a centralized computer can do the above tasks (which took weeks of a highly experienced spectrum engineer to complete) in a few seconds. The spectrum allocation problem is ideally suited for a computer network to solve because it is distributed, multivariate, can easily be solved iteratively, and involves complex predictive methods. By contrast, problems like this are extremely hard for humans to solve manually. Manual solutions take months/years to complete and have very large spectrum allocation “margins” to account for uncertainties and changes. An SDR system can provide for use of these margins because it will continuously vary spectrum allocation to meet the demand.

Below we list the required functions for automated spectrum allocation and split them into categories for the software defined radio and for the network. A software defined radio has to do the following functions to enable spectrum sharing:

1.0 Measure signal parameters

1.1 Detect and measure the amplitude of signals and noise levels relative to each other (absolute amplitude measurements are not required)

1.2 Identify the signal types as primary or secondary

1.3 Determine the duty cycle of signals

2.0 Determine if a primary receiver is in close proximity to avoid adjacent channel or image interference

3.0 Determine the approximate propagation loss from the SDR to the primary receivers in the area

3.1 Transmit specialized "probe" signals that have minimal impact on existing primary signals

3.2 Receive and measure the amplitude of the above "probe" signals

3.3 Conduct these probe measurements with high efficiency to avoid degrading the secondary system's capacity

4.0 Before operation and while operating in the secondary mode, the SDR must

4.1 Vary the secondary signal amplitude over a wide range of values

4.2 Transmit with out-of-band emission signals at a level below values that would cause unintended interference

4.3 Be able to measure the amplitude of the primary signal levels to account for motion of the primary and/or secondary nodes

5.0 Be under reliable command and control of a master controller

5.1 Have a fail-safe function that puts the radio into a safe mode when connectivity to the master controller is lost

5.2 Have security methods that would prevent an unauthorized person from modifying the radio hardware or software

5.3 Avoid transmissions that would interfere with “safety of life” communications even when corrupted commands are sent by the master controller or if the SDR software/hardware faults

6.0 Must be able to determine its location.

The SDR must be connected to a network and network controller that is capable of the following functions:

1.0 Must have a reliable communications link to the SDRs

1.1 There must be a method to communicate with the SDR as a primary user to guarantee that the system “starts up” before secondary spectrum is allocated.

1.2 In normal operation, the link must support a significant level of overhead traffic that occurs at a regular interval.

2.0 Must be able to rapidly and accurately determine which secondary SDR is causing interference to a primary user in case of mistakes

3.0 Must be able to calculate what maximum power level each SDR can use without interference to primary users in each channel of interest

3.1 The available information is the approximate location of all secondary and primary nodes, the measured propagation loss between a subset of the primary and secondary nodes, antenna and other equipment information, propagation models, and terrain information.

3.2 The power calculation must be robust against errors in the above data.

4.0 Must be able to allocate available channels and time slots to each SDR

C. How specifically could it carry out these functions?

The methods to implement the functions required for automated secondary spectrum usage are combination of automating the well-known methods used in spectrum engineering and new technology. Shared Spectrum's vision is that in the near term, secondary spectrum sharing will be accomplished with a homogenous “client server” network optimized for specific bands. The functions are resident in the software defined radio (client) and in the network controller (server).

Adding functions to a software defined radio to enable it measure various signal parameters (amplitude, bandwidth, exact frequency, etc.) requires that modem be able to digitize the baseband signal for a short period and provide the samples to a DSP or other similar processing device. The computation load for this processing is low since it doesn’t occur that often and results are not needed in real time. Using current digital filtering chips the band can be broken into small segments and processed serially. Current low power processing devices have the capacity for this task.

One source of interference occurs when small amplitude transmitter harmonics jam a nearby (~100 m) receiver. Software defined radios need to tune over large ranges of the spectrum in order to make use of spectrum holes, and building broad bandwidth tuners with very low out-of-band emissions is a technical challenge. To reduce the expense of obtaining very low out-of-band emissions, a method to detect the presence of nearby receivers is useful. Shared Spectrum has a proprietary method that we have experimentally verified detects the proximity of several types of receivers.

An important function of spectrum engineering is to conduct propagation tests with the secondary system to verify the propagation assumptions used in the each secondary node's initial maximum transmit power assignments. Another benefit of these tests it that it verifies the approximate location of the secondary transceivers, the secondary equipment configuration (antenna gain, antenna height, output power level, proper frequency, etc.) before the secondary system goes "live". These tests are run at a regular interval to check for changes in the secondary system or unusual propagation conditions caused by atmospheric phenomena. In a mobile system, these tests would be run at shorter regular intervals.

Shared Spectrum anticipates that during these tests, the settings used by the secondary system may occasionally have errors that cause interference to the primary system. These errors can be eliminated using a special technique. In Spectrum Sharing's system, the secondary system uses special proprietary "probe" waveforms that are designed to cause minimum interference to the primary system but are capable enough for probing. These are custom designed for each type of primary signal and are used for probing only. After probing, final adjustments are made to the secondary system parameters, and then the system is used to carry traffic.

Before operation, the SDR must set its maximum transmitter power level to a certain value and be able to operate with out-of-band emissions below certain levels. Methods to achieve these functions are well known.

Once secondary operation is underway, the SDR must continuously monitor the primary signal levels to check for new primary users, changing propagation conditions, or actions taken by the primary system in response to interference. This is difficult because locally the secondary system is operating on the channel of interest and blocks reception of other signals. Shared Spectrum has a cost effective proprietary method that overcomes this problem and has minimal impact to overall system capacity.

Another critical function is that the SDR must be under the control of the master controller during operation and when connectivity is lost, the SDR must revert to a safe operation mode. Technology that provides highly reliable operations of distributed systems is used in military communications systems and in commercial financial systems. Reliable EPROM hardware interlocks can be used to prevent unauthorized operation in certain modes in case of SDR processor failure or reception of corrupted commands. These issues are easily solved using existing technology.

To initialize SDR operation, a reliable method must exist for the "new" SDR to communicate to the master controller. This signaling channel would be used to exchange information related to the SDR configuration to the master controller, for the master controller to provide initial and final channel/power assignments and probe transmission tasking. A general universally available signaling channel between all radios allowing arbitrary, ad-hoc, distributed frequency sharing is still in the future for a variety of technical and policy reasons.

There are many options for the signaling channel function. A primary licensed or unlicensed channel could be used. Or the SDR could monitor a range of secondary channels and identify a secondary channel being used by other SDRs and that was received by the "new" SDR with a high power level. Because the "new" SDR received the transmission with a high power level, the "new" SDR would assume that the other SDR was proximate and already found this channel to be locally available.

Perhaps the most important secondary user function is a method to rapidly and positively identify the cause of any interference problem and be able to correct it immediately. Up to now, this has been the spectrum engineer's nightmare because it takes hours or days to troubleshoot while the entire network is down. This is especially true if the problem is intermittent. However, in a networked secondary system this problem is largely mitigated because at a central point, the master controller can receive detailed spectrum measurements from any secondary node and can independently task the secondary transmitters as required. Shared Spectrum has a cost effective, proprietary method to use the secondary measurements and to control the secondary transmitters to determine rapidly and unambiguously which secondary node is causing interference to of primary systems of various types.

Once the maximum power levels that each secondary node can transmit without interference has been determined, specific channel assignments have to be made that optimize system throughput and minimize the chance of interference. The allocation of the secondary channels is very similar to the allocation of the primary channels except that the frequencies available for each secondary node are not the same and may vary with time. We believe that this additional complication can be overcome with a straight forward extension of the existing frequency assignment techniques.

D. What are the benefits of the spectrum sharing arrangements described above, and what steps might we take to permit the use of software defined radios to enable such sharing arrangements?

The primary benefit of secondary usage is greatly increased wireless capacity, for improving connectivity to the Internet for mobile users and fixed users where line-of-sight links are not appropriate due to terrain blockage.

Section II above describes the public benefits that would ensue if the Commission allows secondary spectrum usage in the TV bands. We believe that similar or larger capacity gains are possible as the results on sharing in the radiolocation bands, and by piecing together small allocations in almost all of the other bands except for GPS and several safety-of-life FAA bands.

Chairman Kennard has emphasized "the need to encourage secondary markets for underused spectrum."[3] We suggest that the Commission immediately approve technical testing of the secondary spectrum usage in the TV bands as described above. It should exercise its authority under Part 5 and under Section 2.102(a)(3) of the Rules, to grant an experimental license to enable Shared Spectrum Company to demonstrate its system. The Commission should waive any present rules that prevent this innovation. The FCC should allow total freedom on what waveforms and protocols are used. Metrics to measure capacity and residual interference will be developed. The capacity of the system to handle mobile nodes will be established. The tests must be large enough scale so that the area simultaneously covers multiple TV station coverage areas and involve a large number of users because many of the issues and proposed technical solutions only occur with a large network.

[3] Address to the Cellular Telecommunications Industry Association, February 28, 2000, p.4.

The Commission should then begin the process of removing possible impediments to full operational implementation in Part 2 of the Rules. With respect to the TV bands, as the initial example, it should permit fixed and mobile services as secondary users. The ITU allocations for all of the TV bands, already provide for at least secondary allocations for fixed and mobile services.[4] Currently Part 2 provides for use of the TV bands for other services is limited to subcarriers, vertical blanking intervals and subscription services.[5] As a follow-on step, the Commission should review the allocations to all spectrum services below 3 GHz to add at least secondary allocations for other services to open up the spectrum for efficient secondary use. As Commissioner Furchtgott-Roth has noted, "Secondary markets allow initial allocations to be modified so that spectrum is available to those that value it most."[6]

After the initial spectrum sharing tests under experimental license provide proof that the technical issues are resolved, then the Commission should permit expanded field tests over a larger area that involves multiple existing primary users. It can also use that opportunity to gain data to help resolve business and legal issues between existing primary users and secondary users before secondary usage becomes a major economic factor. As Chairman Kennard has observed, the Commission "can find ways to allow potential

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[4] Fixed and mobile services have secondary status throughout Region 2 in all TV bands in Region 2, with the exception of 512 to 608 MHz (for TV Channels 21 to 36). But under Note 678, these non-broadcast services have primary status in the United States in the 512 to 608 MHz band.

[5] See Notes NG149, NG142 and NG128 to Section 2.106 of the Rules.

[6] Statement Regarding FCC's Public Forum on Secondary Markets in Spectrum, May 31, 2000.

'buyers and sellers' to come together."[7] The most appropriate answers may not be identified before the technical experiments are performed. It is imperative that transactional costs characteristic of the very limited spectrum sharing of the past are not allowed to destroy the inherent technological efficiencies of a system that makes decisions in a fraction of a second based on programmed instructions. As the new technology unfolds, the Commission can direct the collection of usage data that can be used for economic distributions based on well chosen and representative samplings. Rules needed to allow the secondary market to operate efficiently by establishing standards for programmed instructions establishing allocation priorities can be then incorporated in a new part of the Commission's Rules.

The important thing is to recognize that there is no "loser" in what we propose and that all parties will work together to bring this technology forward. The present spectrum users have enormous incentive to make better use of the resource and there is tremendous benefit to all the American people.

E. What changes may be appropriate for the way the Commission currently allocates spectrum? If changes are warranted, how could we make the transition for the current allocation and licensing model to a new model?

There are likely to be two stages in radio network development that should prompt the Commission to consider new frequency allocation methods. The first development will be secondary usage as described above where a networked secondary system can co-exist with primary users. (1) There will be a need for the FCC to reduce transaction costs

[7] Address to the Cellular Telecommunications Industry Association, February 28, 2000, p.4.

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by standardizing the property and contractual issues/agreements. The transactional arrangements for a secondary license market must be very efficient because of the many players involved. (2) The FCC may want to consider some method to allow secondary usage without the explicit individual contracts with every primary license holder. Primary users would have the opportunity to use the spectrum with lower cost equipment without causing interference within his allocation. Secondary users would be allowed to use the spectrum on the condition of not exceeding prescribed interference limits to the primary user.

The second stage of radio network development will occur when the cost of broad band tuners and waveform agile SDRs are low. When this occurs, frequency will not be a critical aspect of spectrum allocation important except for a few cases like GPS, radar, astronomy, and some high power applications that will not be frequency agile until a later period. Almost all communications will be frequency agile and will involve an expensive, distributed, cellular, fixed distribution system. To obtain good performance in high multipath environments, wide bandwidth (> 20 MHz) waveforms will be used. These systems will be able to mitigate interference and will not require primary status to operate.

VI. **CONCLUSION**

The industry stands at the threshold of a major expansion of communication capacity to meet the nation's needs at a time when communications services are expanding at a dramatic rate and the need to overcome spectrum insufficiency has reached urgent levels. SDR technology has a pivotal role to play in this expansion. The Commission should encourage it by granting experimental licensing to demonstrate the enormous benefits it can bring and leading the transition to a more modern and efficient use of the spectrum.

Respectfully submitted,

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